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6. AUTHOR(S) Geoffrey W. Taylor; Eric Donkor				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Connecticut Dept. of Electrical & Systems Engineering U-157 260 Glenbrook Road Storrs CT 06269-2197		8. PERFORMING ORGANIZATION REPORT NUMBER		
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13. ABSTRACT (Maximum 200 words)  The opto-electronic development program has moved forward substantially during the last year. In the 100GHz receiver program with Wright Patterson Air Force Base, new approaches to the implementation of high speed lasers and detectors have been devised. These structures include transmission lines with phase velocities matched to the group velocity of the optical waveguide to eliminate the limitation of the device capacitance and output impedance. A new process sequence has been developed to minimize parasitic capacitance through the use of the natural oxidation of Al containing compounds. A phase mask technology has been implemented to produce laser gratings. A complete test mask has been produced to evaluate the traveling wave concept. The SBIR program to produce neural network building blocks with the inversion channel technology is now underway. The Inversion Channel Process technology to build these circuits is identical to the other program although the emphasis here is to produce integrated chips which are coupled by free space transmission. Measurements of the nonlinear index in the fiber of $1.8 \times 10^{-17} \text{ m}^2/\text{W}$ have been obtained. The erbium doped fiber laser has produced stable pulse trains of 10ps pulses at data rates of 500MHz. The mode locked sources can now be used with the optical Kerr switches to realize all optical components.				
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## ◦ FINAL TECHNICAL REPORT

US ARMY Grant No. DAAH04-95-1-0433

Title: Bit Error Rate Testbed for Multigigabit Optical Communication Network and High Performance Optoelectronic Devices

The objective of this research program was to develop integrated versions of optoelectronic devices so that integrated circuits using these technologies can be applied to a range of DOD and commercial applications. This program is supported by three other DOD efforts in high speed optical switching and in integrated optoelectronics. The first of these was a one year effort to devise an optoelectronic approach to realize a transceiver with a frequency capability of 100GHz. This was sponsored by the Wright Patterson Air Force base and was intended to extend the work accomplished in previous programs conducted on this technology at AT&T Bell Laboratories. The second of these was an SBIR phase II program sponsored by the Rome Air Force Base on the use of optoelectronic circuits in Optical Signal Processors. The intent of this program was to introduce the inversion channel technology as a candidate to implement a set of building blocks which could then be used to assemble an optically connected neural network. The third program was one to use erbium doped fiber lasers in conjunction with all optical switching devices to implement a high speed all optical network. Thus the fiber laser was to become a stable high speed pulse source which could be modulated by an independent optical switching arrangement. The highlights of the three programs will now be reviewed.

### 1. 100 GHz Optical Transceiver Program

This program got underway in October 1995. The program was awarded on the basis of two new concepts for high speed detection and emission. In previous programs for the Air Force the inversion channel technology was developed as a baseline technology for monolithic integrated optoelectronic circuits. As a starting point for this program therefore we used the technology platform for the Inversion Channel Technology (ICT). This platform produces HFET E/D logic, HFET lasers, HFET detectors and HFET modulators as integrated devices. We had already demonstrated the essential integratability of these components as vertical cavity devices. The laser had been built as a 10um device with a 2mA threshold in the form of the switching laser. For the demonstration as a non-switching laser a new implant technique is required and this was to be investigated under the present program.

In this effort the goal was to achieve close to 100GHz operation in a transceiver which thus demanded 3db cut-off frequencies for the detector and the laser in the regime of 100GHz. For the high speed detector it was proposed to use the same vertical cavity resonant enhanced structure already devised within the ICT to achieve near to 100% absorption in a quantum well light for light oscillating normal to the surface. However the light should be introduced to the structure via a waveguide and a novel grating arrangement was designed to couple the waveguide light into the resonant cavity. The

baseline detector structure that is used as the starting point is the HFET photodetector with one alteration. In the initial detector experiments, the collector below the quantum wells was used to gather the photoholes (the photoelectrons flow to the two drain nodes). In the modified high frequency design the gate would be biased negatively to collect the hole current in the gate terminal. Then the gate and the drain nodes are essentially at the same elevation and may be used as the positive and negative electrodes of a coplanar transmission line. Therefore the concept is one of an optical wave traveling through the structure and that the traveling optical wave produces a traveling electrical wave on the coplanar transmission line. By matching the velocities of these two waves, it is possible to produce extremely narrow pulse response.

For the high speed laser, a similar approach was adopted. The structure is essentially identical to that of the detector. The light produced within the vertical cavity is coupled into the waveguide by a grating. The waveguide couples the light to the edge of the chip. The electrical drive signal for the laser is introduced as an electrical traveling wave on the coplanar transmission line and propagates down the coplanar line at essentially the same speed as the optical wave is traveling in the guide. Because the two waves are closely matched in velocity, then a very fast laser pulse response is possible.

These two devices are fabricated in the inversion channel technology which provides the technology platform to produce FET or bipolar devices in addition to the optical devices. Therefore electronic control devices are available for modulation and demodulation.

During the first year of this program, the laser and detector were designed and a mask set was produced. Considerable effort was expended in this design since a revised process sequence requiring about 14 levels of photomask was required. In addition a new mask level was introduced to form the grating pattern. Special tooling using the new phase mask technology was required. Device dynamic response was simulated and it was shown that 100GHz operation was indeed achievable. Also several MBE wafers were prepared using the inversion channel structure. For the fabrication, a new clean room facility was designed and several major pieces of equipment were assembled. The clean room is now coming on line and fabrication is about to begin. The program time line with the Air Force has been extended by six months until March 1996. Therefore during the period from September to March, wafers will be fabricated and the device concepts will be tested.

## 2. Optical Signal Processors in the Inversion Channel Technology

The goal of this phase II SBIR program with Rome Air Force base was to demonstrate the feasibility of building the neural network elements with the ICT. The building block for the neural network is the neurode. This is a circuit which accepts many inputs from various physical locations and performs a sum. However, the sum is a weighted sum with the weighting factor being an adaptable quantity which is changed according to the learning algorithm which one desires to implement with the circuit. As an optical processor, the inputs to the circuit are optical. However, the weighting is accomplished most practically

in the electrical domain. What the inversion channel technology provides is an optical detector with an independent third terminal which can be used to linearly control the detector response. It is therefore the ideal way to weight the input. The optical signal is converted to photocurrent and weighted within a single device. The determination of the weighting signal, of course, is another problem which must be accomplished by additional processing which may also be achieved with the inversion channel components. The weighted signals are summed electrically and thresholded. The resulting thresholded output is converted to an optical signal for propagation to a subsequent layer of the neural processor. Once again the ICT provides an optimum solution to this problem because of the natural thresholding characteristics of the nonlinear devices. Two approaches are available. First, the inputs can be summed directly into the gate of an FET and when the voltage exceeds the inverter noise margin, then the inverter output will move rapidly from a 1 to a zero. In the ICT, this circuit is implemented within analog devices including the HFET, HFET laser and HFET detector. However another approach has also been identified by using the digital switching technology which is constructed around the DOES device. The DOES device is a thyristor which is thresholded with an optical input or with a small electrical current delivered to its third terminal. Therefore it is natural to use the DOES as the thresholding device since it performs as a hard limiter at a critical input threshold. The DOES also functions as a laser. However, it is more practical to use the DOES only to perform the thresholding function and to use the HFET laser as a load device to direct the optical output to the appropriate port. It was shown that the DOES device is the optimal way to implement the Kohonen network which requires the winner take all function.

The SBIR phase II proposal was submitted in November, 1994, and the phase II was expected to start in June 1995 almost at the same time as this equipment contract. However, the program was deferred for one year and was finally awarded in August 1996. The work is just now getting underway and we expect to have functioning neural network circuits by June 1997.

#### Publications/Conferences

1. Inversion Channel Optoelectronics from a Manufacturing Perspective, G.W.Taylor and S. Jiang, Proc. of the Conference on Manufacturing Process Development in Photonics, Huntsville, AL, Nov. 1-2, 1994.
2. Inversion Channel Vertical Cavity Double Heterostructure Switching Lasers, P.A.Evaldsson, G.W.Taylor, S.Jiang, P. Cooke, Electronics Letters, Vol. 31, No. 11, pp 920, 25 May 1995.
3. Integrated HFET's and HFET Lasers Utilizing Carbon Doping, P.A.Evaldsson, G.W.Taylor, M.Micovic, R.Malik, and S.Jiang, IEEE Photonics Tech. Letters, Vol. 8, No.3, pp370, 1996

### 3.Multigigabit All-Optical Network

This program was to develop enabling components such as fiber lasers and all-optical modulators for implementing high speed optical communication testbeds. This testbed will enhance a 5 Gb/s Time Division Multiple-Access optical network developed jointly with the Photonics Research Laboratory at Rome Labs. Thus far we have fabricated an in-line fiber laser operating at 1550nm. We achieved passive mode-locked pulses with a pulse width of 60ps at a repetition rate of 200MHz by using a coupled cavity Er-doped optical laser with in-fiber gratings.

As a first step to developing an all-optical high speed modulator, we have successfully fabricated a highly nonlinear CdSSe-doped specialty fiber. We measured the linear absorption coefficient of the fiber, and found it to be 14dB/m at 1550 nm. Also using Z-Scan method, we measured the nonresonant, nonlinear refractive index of the fiber as  $1.8 \times 10^{-17} \text{ m}^2/\text{W}$ . This value is four hundred times higher than silica fiber. At the time of writing this report we were using the specialty fiber as a Kerr medium to develop an optical switch. These activities led to a number of publications and one patent as listed below.

#### Patent Disclosure

1.E.Donkor, R.Boncek, "Grating-assisted all-optical switching in semiconductor-doped nonlinear fiber", invention disclosure, filed at the University of Connecticut Technology Transfer Office, Sept.27, 1995.

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1. E.Donkor, "A Kerr nonlinear fiber with in-line fiber grating structure for all-optical switching", CLEO Pacific Rim Conf. July 10-14, '95, Chiba, Japan
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3. P.K.Cheo, L.Wang, M.Ding, "Low threshold, self-tuned and passively mode-locked coupled-cavity all-fiber lasers", IEEE Photonics Tech. Letters, Vol.8, pp.66-68, 96
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